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TOPICAL REPORT

AN INVESTIGATION OF MECHANISMS OF MOBILITY CONTROL AND CRUDE OIL DISPLACEMENT BY CHEMICAL ADDITIVES IN STEAM DRIVE OIL RECOVERY TECHNIQUE

by

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ABSTRACT

A two-dimensional steamflood assembly has been designed, fabricated, and interfaced with computer. This assembly will be used to investigate the mechanisms of mobility control and crude oil displacement by chemical additives in the steam drive oil recovery method. A series of linear steamflood experiments have been conducted to develop a laboratory technique for evaluating steamflooding of heavy crude oils.

INTRODUCTION

Steamflooding is the most widely used EOR method. Daily production in the USA by steamflooding now exceeds 400,000 B/D of oil. The 1984 EOR report by the NPC projects an advanced-case recovery of over 10 billion barrels by thermal methods, most by steamflooding. Despite the commercial success of this method, its recovery mechanisms have not been completely defined and it is expected that commercially significant improvement can be made.

During the last few years, the DOE has successfully demonstrated, through laboratory and field tests, that chemical additives can economically enhance the performance of steamflooding. Even more questions now arise as to how these additives, when combined with steam, work to recover additional oil.

The focus of the DOE Heavy Oil Program has shifted from the screening and testing of possible additives to the investigation of the underlying recovery mechanisms. This project is directed initially toward the use of surfactant additives, but included in the investigation are studies that pertain to the basic recovery mechanisms of the steamflooding process itself and so to improvements.

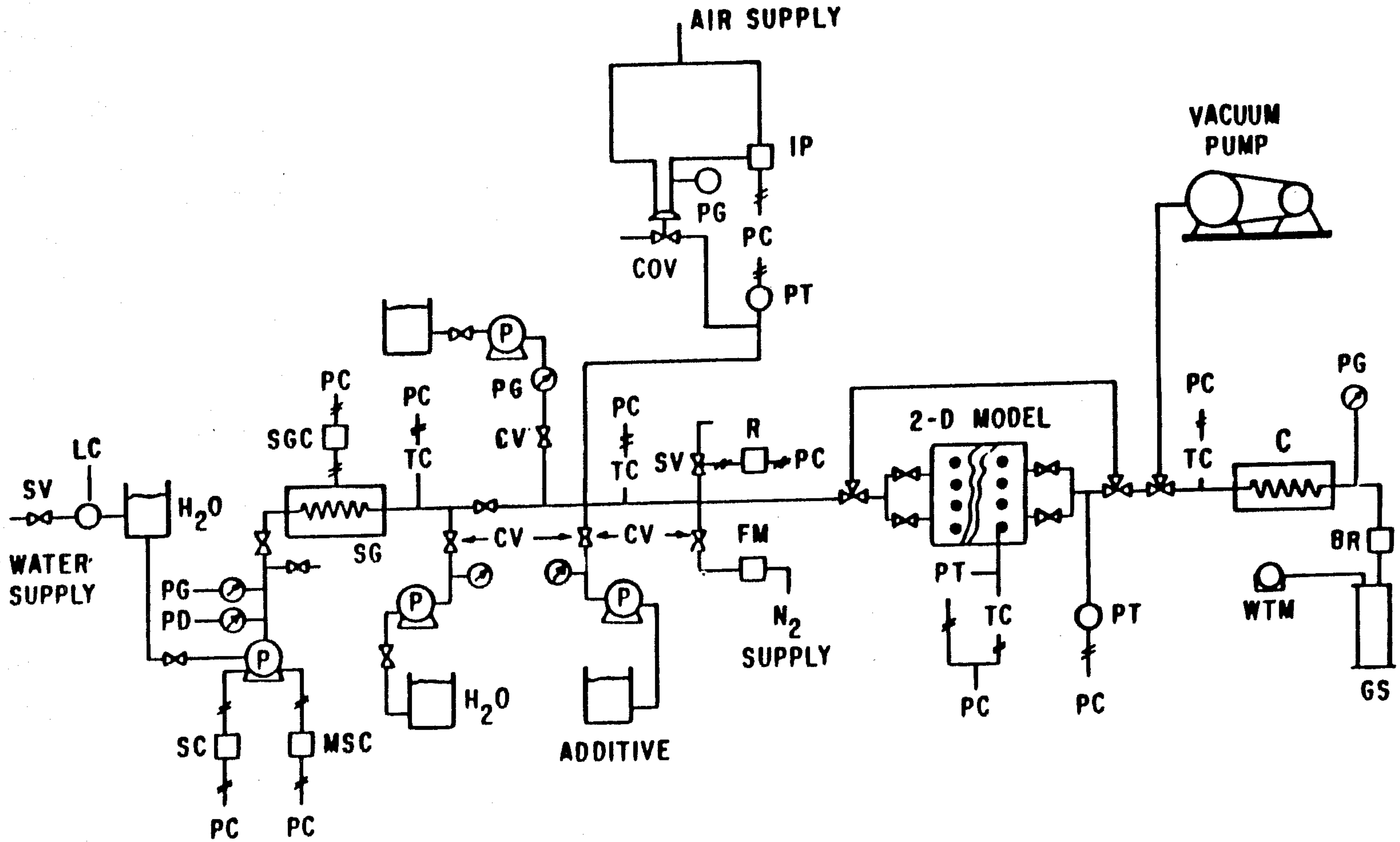
A key component of the DOE program is the operation of a 2-D physical steamflooding model. The model should demonstrate an acceptable representation of the steamflood process and incorporate effects of steam override. A truly dimensionally scaled model is not necessary because of added complications and the nature of the factors under investigation. The NIPER 2-D model, completed and made operational in the first year of the project, is an important research tool in describing the steamflood and steamflood with additives processes. The ultimate goal of the work is to determine basic mechanisms of oil recovery using additives with steam. This knowledge should enable industry to better predict the performance of additives and lead to full field application of the technology, and thus, reduce the risk and improve the economies of field applications.

This is the second year of a four-year project. During FY85, NIPER developed one-dimensional (linear) and two-dimensional steamflooding experimental facilities. The one-dimensional facilities included consolidated and unconsolidated coreflood units. These facilities are expected to enable the investigation of gravity override and viscous fingering phenomena as it effects oil recovery performance. Experiments will be conducted in FY86 to determine the ability of surfactants to improve steam volumetric sweep facilities using the 2-D steamflood assembly. This objective can be met by detecting the steam zone and therefore its progression pattern.

TWO-DIMENSIONAL STEAMFLOOD ASSEMBLY

A schematic diagram of the 2-D steamflood unscaled model is shown in figure 1. The model, which is made of 304 stainless steel, has the internal dimensions of 24 inches long x 6 inches high x 1.5 inches wide. To prevent erroneous temperature readings caused by conduction of heat through the metal walls, the inside of this model has been insulated with a zircon base refractory cement of 3/8 inch thickness. The thermal conductivity of the insulation cement is 3.41 Btu/sq. ft/°F/in, which is much less than 113 Btu/sq ft/° F/in. of steel. The thermal expansion coefficient of the cement, 4.6 x 10^{-6} in/in/°F, is comparable to that of the steel, 6.5×10^{-6} in/in/° F. On the inside of one of the 6 inch x 1.5 inch wall of the model, a moveable, resilient rubber pad, ethylene propylene terpolymer, has been provided to eliminate steam bypassing through any void space between the sand surface and the wall of the model. Two ceramic distribution plugs at the inlet and the outlet of the model have been provided. These distribution plugs are designed so that selective introduction of a fluid in the upper half, the lower half, or throughout the entire vertical cross section of the model is possible. To prevent sand from migrating into the tubing, 270 mesh size screens have been attached to the face of each of the above distribution plugs. In addition, a 1/16 inch viton sheet has been attached to the inside surface of the lid, 24 inch x 6 inch, to keep the sand from migrating to undesired areas, such as over the distribution plugs.

FIGURE 1. - Schematic diagram of 2-D steamflood experimental assembly.



BR - Back Pressure Regulator
C - Condenser
COV - Control Valve
CV - Check Valve
FM - Flow Meter (Gas)
GS - Graduated Cyclinder
IP - Current/Pressure Converter
LC - Level Control

MSC - Motor Speed Control
P - Pump
PC - Personal Computer
PD - Pulsation Dampener
PG - Pressure Gauge
PT - Pressure Transmitter/
Pressure Transducer
R - Relay

SC - Stroke Length Control
SG - Steam Generator
SGC - Steam Generator Console
SV - Solonoid Valve
TC - Thermocouple
WTM - Wet Test Meter

This model withstands a maximum operating pressure of 200 psig which corresponds to 387° F saturated steam temperature. The model is equipped with thirty-two ports. Presently, thirty two thermocouples, one in each port, and ten pressure transducers distributed throughout the model have been installed. These temperature and pressure readings throughout the model will enable one to detect the steam zone and its progression. Thus, the reduction of steam mobility and the diversion of the steam front in the presence of foams and/or emulsions can be observed. A positive displacement pump is used to pump the water from a water supply tank, equipped with a level controller, into a coil placed inside a tube furnace. The flow rate of this pump can be set by a combination of motor speed and stroke length adjustments. The tube furnace is used to generate superheated steam. Superheated steam will be converted to saturated steam of desired quality by addition of water using a metering pump. Another metering pump is used to pump surfactant slugs into the injected steam. The volume of nitrogen gas to be injected following the surfactant injection is measured by a gas flow meter. Two pressure transmitters at the inlet and outlet of the model measure steam injection and discharged fluid pressures.

The above steamflood assembly is interfaced with an IBM PC/XT* computer. Temperatures and pressures along the model, superheated steam temperature, saturated steam temperature, discharged fluid temperature, injected steam pressure, and discharged fluid pressure are recorded by the computer at specified time intervals. Additionally, the steam injection pressure is controlled by the computer. This latter task is performed using the inlet pressure transmitter, the I/P transducer, and the control valve. A computer program has been written to accomplish the above tasks, i.e. data acquisition and injection pressure control. A safety system using a combination of a solenoid valve and a relay has been provided and interfaced with the computer.

The component testing of the steamflood assembly has been completed. The following components were tested: the water pump used to pump water into the tube furnace, the tube furnace, the thermocouple and pressure transducers, the pressure transmitters, the I/P transducer, and the control valve.

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*References to specific products does not imply endorsement by NIPER.

A set of equations has been written for the heat balance computation of the 2-D model. This set includes the heat injected by steam, heat stored in the steam zone, heat loss to the ambient air, heat transferred from the steam zone to the liquid zone ahead of the steam zone, and the heat stored in discharged fluid. This set of analytical equations will be used to determine thermal efficiency of the model during steamflood experiments. Based on some assumptions, it was found that the thermal efficiency of the model was low. Hence, external insulation of the model was warranted. Experimentation will be required to determine the degree of improvement the external insulation provides.

A sandpacking technique has been developed for packing of the 2-D model. Sand is added in increments to a feeding hopper which can be connected to the model through four ports provided in one of the 24 inch x 1.5 inch walls. The model placed in test (vertical) position is vibrated with an air turbine vibrator (7200 VPM, vibration per minute, frequency and 500 lb impact force at 80 psi air pressure) while being filled with sand. To keep the sand from bridging in the feeding hopper, a second air turbine vibrator (1200 VPM frequency and 20 lb impact force) is attached to the feeding hopper.

The model was packed with silica sand (screen analysis is given in table 1) using the above technique. Initially, the 7200 VPM vibrator was directly clamped to the top center of the model. However, it was necessary to vibrate along the length of the model to achieve a uniform packing throughout the model. Water was then injected into the model to completely saturate the sandpack. A satisfactory porosity in the range of 30-33 percent was achieved. A temporary lid made of plexiglas was installed in the model to help visualize the entire packing process and the saturation procedure as well.

ONE-DIMENSIONAL STEAMFLOOD

To develop a technique for steamflooding of heavy crude oils, several steamflood experiments have been conducted using the one-dimensional steamflood apparatus. The details of the apparatus are given elsewhere (1). A Hassler type core holder with a viton sleeve enclosing the core was used. The annulus space between the viton sleeve and the core holder was filled

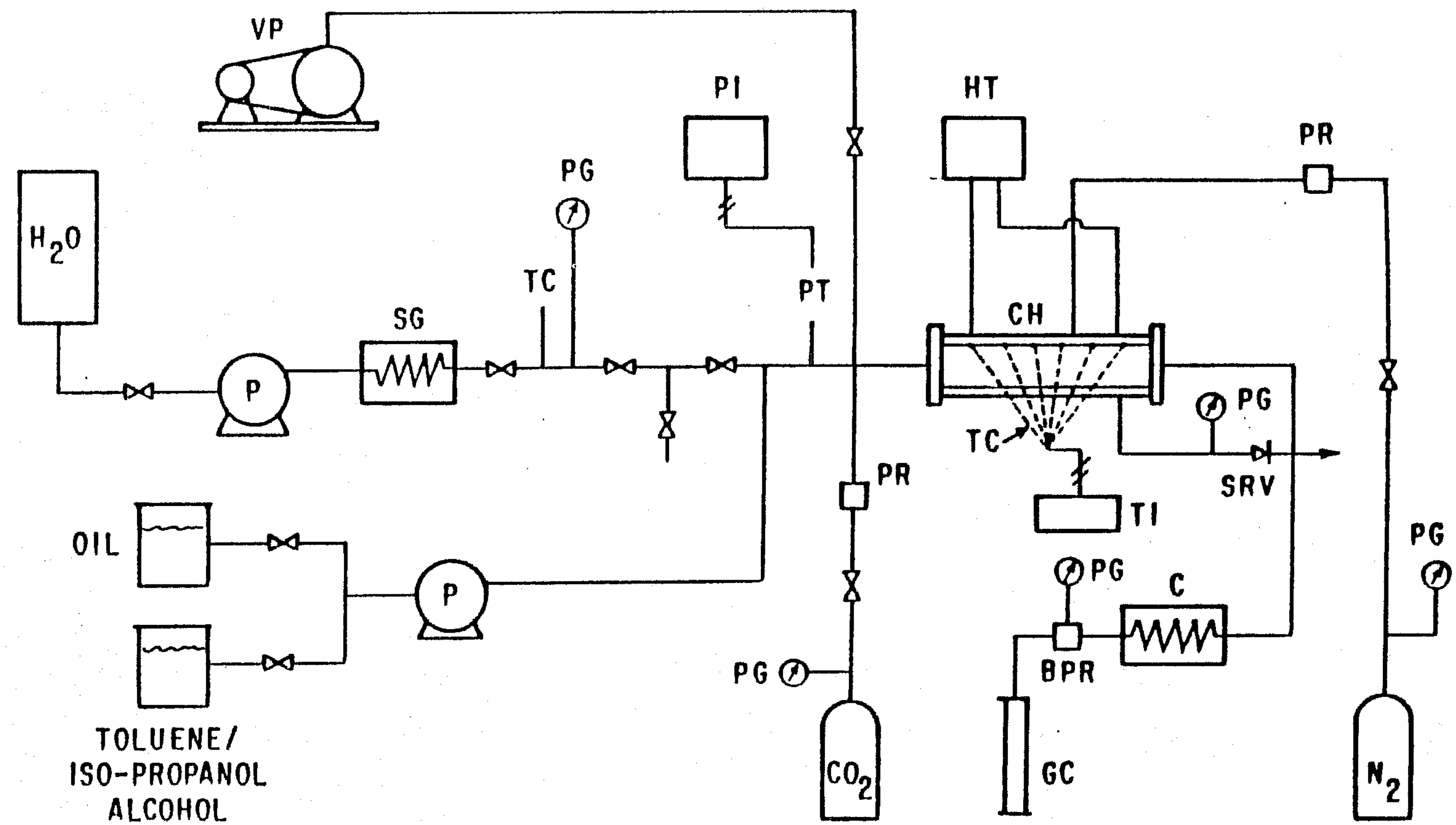
TABLE 1. Silica sand size distribution

Percent	Mesh size
2.5	≤ 80
26	100
37	120
28	140
6	170
.5	≥ 200

with a mineral oil pressurized with nitrogen to eliminate channeling around the core and to simulate overburden pressure. The schematic diagram of the linear steamflood assembly is shown in figure 2. Berea sandstone and Cottage Grove cores of 1.5 inch diameter by 24 inch length were used. These cores were fired according to the procedure given in reference (1) to deactivate the clay minerals contained in the cores. A typical analysis of the above rocks, i.e. Berea Sandstone and Cottage Grove is shown in table 2. Chaffee crude oil was used in all the tests. The properties of this oil is listed in table 3.

After the insertion of the fired core into the core sleeve, a vacuum pump was used to remove the air present in the core by following the cycle of vacuum with CO_2 injection repeatedly. Then a one percent by weight sodium chloride brine was injected into the core and the porosity and the absolute permeability to brine were measured. After the saturation of the core with several pore volumes of brine, Chaffee oil was injected to achieve irreducible water saturation in the core. During the oil injection, the core was heated to about 100° F by a heat tape wrapped around the core holder. The reasons for this initial heating of the core were to: 1) simulate reservoir temperature and 2) facilitate the injection of the crude oil into the core within an acceptable time period. Saturated steam at initial injection pressure of about 300 psig was used in all the runs. The overburden pressure of at least 700 psig was maintained throughout each run. Temperature readings at the top surface of the core at six different locations of four inches apart were taken periodically during the runs in order to follow the steam front. In addition, the steam injection pressure and temperature and the discharge

FIGURE 2. - Schematic diagram of linear steamflood experimental assembly.



BPR - Back Pressure Regulator
C - Condenser
CH - Core Holder
GC - Graduated Cylinder
HT - Heating Tape

P - Pump
PG - Pressure Gauge
PI - Pressure Indicator
PR - Pressure Regulator
PT - Pressure Transducer

SG - Steam Generator
SRV - Safety Relief Valve
TC - Thermocouple
TI - Temperature Indicator
VP - Vacuum Pump

pressure and temperature were periodically recorded. All the runs were terminated after steam breakthrough.

TABLE 2. Elemental analysis of rocks

	Berea Sandstone	Cottage Grove Sandstone
SiO_2	84.6	84.6
Al_2O_3	4.5	4.7
Fe_2O_3	1.4	1.2
MgO	0.5	0.08
CaO	0.8	0.08
TiO_2	0.2	0.1
SrO	0.03	0.01
K_2O	2.1	0.4
Na_2O	2.2	2.9
Mn_2O_3	0.06	0.07
SO_3		
Loss on Ignition	2.6	1.7
Kaolinite	7.0	6.0
Chlorite	0.0	1.0
Illite/Mica	4.0	6.0

RESULTS

Three, 1-D steamflood experiments were conducted. The results of these experiments have been summarized in table 4. Comparison of the first test with the other two tests is not appropriate because during the first test, steam was injected in cycles of different flow rates in an increasing order, 50-150 cc/hr of water equivalent and a back pressure of 30-50 psig range was maintained. On the other hand, a constant flow rate of steam, 125 cc/hr of water equivalent, and atmospheric back pressure were used in tests number 2 and 3. To verify the reproducibility of the above steamflood tests, test number 3 was conducted under similar conditions as test number 2 by using the same core used in test number 2. This core was successfully cleaned and

TABLE 3. Chaffee crude oil properties

API Gravity	18.2
Viscosity at 72° F (cp)	290
Acid Number (MgKOH/g sample)	1.4
Asphaltenes (wt%)	5
Polars (wt%)	40
Saturates (wt%)	8
Aromatics (wt%)	47

the initial porosity and the absolute permeability to brine were established. The cleaning process involved several cycles of injection of isopropanol followed by toluene, each of several pore volumes. A significant amount of the oil recovered was in the form of oil-in-water emulsions. The recovered oil and brine were separated by centrifuge technique.

SUMMARY

As shown in table 4, the duplicate test number 3 compares well with the test number 2 with the exception of the total volume of the injected steam which is significantly higher in the duplicate run. Since this steam quality was not controlled in these tests, it is thought that the difference in the total injected steam was caused by different steam qualities used in tests number 2 and 3. In addition, due to the difficulty encountered in establishing the steam zone and its progression during a run, it is recommended that cores of higher absolute permeability (at least 500 md) and pre-fixed steam quality be used in any future run to obtain more consistent results.

TABLE 4. Results of linear steamflood tests

Test No.	Core Material	Porosity (%)	K_{brine} (md)	S_{o_i} (%)	S_{o_f} (%)	Oil Recovery (% IOIP)	Injected Steam H_2O Equivalent (PV)
1	Cottage Grove	28	220	66	26	60	12
2	Berea Sandstone	17.5	85	80	24	72	12
3	Berea Sandstone	17	72	77	22	71	22

ACKNOWLEDGMENT

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REFERENCES

1. Madden, M. P. and P. Sarathi. Light Oil Steamflooding Core Flood Experiments. DE-FC22-83FE60149, Topical Report, NIPER-44, March 8, 1985.